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FINAL REPORT ON A SERIES OF STUDIES ON THE DESIGN
REQUIREMENTS FOR A REAL-TIME INFORMATION AND COMPUTATIONAL
SYSTEM TO ASSIST R&D MANAGEMENT IN THEIR PROJECT
SELECTION* DECISION-MAKING

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R E C E I V E D

The research described in this paper represents the work of the Northwestern "project selection" research team. Members of the research team who have contributed to the work described here are: Albert H. Rubenstein (Principal Investigator), Norman R. Baker, R. Patrick Forster, Arthur P. Hurter, Jr., Daniel L. Kegan, Jon A. Larson, P. Michael Maher, Hans-Horst Schroeder, and Richard W. Trueswell.

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FINAL REPORT ON A SERIES OF STUDIES ON THE DESIGN REQUIREMENTS
FOR A REAL-TIME INFORMATION AND COMPUTATIONAL SYSTEM TO ASSIST
R&D MANAGEMENT IN THEIR PROJECT SELECTION DECISION-MAKING

Purpose

The purpose of this paper is to report on a series of studies currently underway at Northwestern University. The studies are part of a long term project aimed at specifying the design requirements for a real-time, computer-aided, information system for the selection, review, and evaluation of research and development (R&D) projects. Specifically the report focuses on phases of the research which have been supported by the Office of Naval Research.*

Scope of the Study

Since 1959, Northwestern University has had, under the direction of Professor Albert H. Rubenstein, a Program of Research on the Management of Research and Development. The program consists of approximately a dozen individual projects or subprograms, focused on specific aspects of the R&D process. Among the subprograms (each consisting of a continuing series of staff studies and graduate theses) are studies of the effects of decentralization on R&D, organization of R&D in newly developing countries, the generation and flow of ideas in R&D, the information-seeking behavior of researchers, and project selection in R&D.

The latter study is the subject of this paper. This study, which focuses on the project selection process in R&D, was formally initiated in 1965. It has four interrelated objectives: **

1. Improve the present understanding of the information requirements for improved project selection and review in R&D.
2. Analyze top management's information requirements and criteria for project selection and approval.
3. Test and evaluate formal information systems and models (generally mathematical) that have been proposed in the literature for project selection.
4. Attempt to specify the requirements for a useful real-time information system for project selection and review.

In pursuing these objectives, studies have been undertaken at three large industrial organizations and at two large governmental R&D organizations.

* Office of Naval Research, Research Grant Nonr-1228-638 from 1965-1969

** Source: Original proposal to ONR (Our document number 65/24)

A Premature Termination at One Site

A substantial amount of our research effort in one large industrial R&D facility was limited to the development of a methodology for studying the project selection process. Some of the methodological problems involved:

1. Identifying events which are often diffused throughout an organization and which are spread over an extended time period.
2. Identifying individuals who are involved in these various "project selection" events.
3. Obtaining actual criteria which decision makers use during these events.
4. Reconstructing the information state of decision makers at the time of these events.

Some of the procedures and techniques developed during this study reflect a conscious attempt to minimize:

1. The distortion in the study data due to a lag between the occurrence of an event and the recording of data relevant to the event.
2. The annoyance of the people being sampled.
3. The effect on behavior resulting from asking subjects to examine frequently their actual behavior.
4. The expenditures necessary to achieve an acceptable number of field observations.

Unfortunately, much of this investment in methodology could not be recouped at this particular field site as the laboratory management found that they were unwilling to continue their participation into the experimental phase of the study. Accordingly, further research at the site was prematurely terminated (68/D, 67/2)*.

A Series of Studies at One Site

At another large manufacturing firm, three studies were undertaken. These studies focused upon the project selection decision and the procedures by which projects are evaluated (69/23, 68/2, 67/55, 67/45).

In the first study the stability and sensitivity of three economic decision models was investigated. Tests were performed on a portfolio of 51 projects undertaken by the firm. Three vectors were considered: research expenditures, capital investments, and excess value anticipated for each of the 51 projects. Each

*These numbers refer to our program documents. A listing of these documents is attached.

vector was examined at each interval of a 10 year planning horizon.*

The decision models investigated were (1) a marginal efficiency of capital model, (2) an excess current value model, and (3) an excess terminal value model. The results indicate that the models were stable and sensitive to systematic variations of (a) anticipated excess value of each project over their planning horizons, (b) the length of the planning horizon, (c) the reinvestment rates of interest associated with each planning interval, (d) the capitalization rates of interest (i.e., the opportunity cost for investment resources) relevant to the planning intervals, and (e) the method used to adjust for risk.

In a second study at this field site an attempt was made to study the relation between analysis and decision, or between analysts and decision makers. The second study differs from the first study. The first study sought to examine, in an empirical context, the logic implicit in three economic decision models. The second study sought to situate this logic in relation to the actual decisions made by the organization's decision makers. Specifically, reasons for the divergence between the results of the analysis and the results of the actual decision making process were hypothesized and tested.

The predictive criteria for this divergence were (1) the perceived long term contribution to the economic value of the firm, (2) the perception of a relative priority of project importance, and (3) the perceived project urgency. Additional perceptual data was gathered on criteria which were not found to contribute to the explanation of this divergence. These criteria included (1) the amount of investment resources previously consumed by the project, (2) whether the project was in the exploratory, developmental, or design phase of research, (3) the laboratory in which the research activity was being performed, and (4) the apparent interest of key members of top management.

* For this study each project was provisionally assumed to be independent and to compete individually for funding or continued funding from an unlimited fund of research investment resources. The consequences of relaxing these assumptions are still being investigated.

A third and final study at this field site attempted to focus upon scoring models and preference functions as a means to discriminate between projects.

For this study a scoring model was used at the laboratory level and the predictive ability of the model was assessed in light of a final project selection decision made at the firm's corporate headquarters.

The overall rationale for assessing the predictive ability of scoring models is that inherent in the present structure of such models, no attempt is made, in general, to specify a system which describes the behavior of a decision maker, even though portions of such a system are implied by the way project scores are achieved. Specifically, it can be argued that scoring models state the form of a preference function as an assumption rather than deriving it from a set of behavioral axioms.

The model used in this study required subjective estimates by one or more evaluators of six different project attributes. A project score which was to be the product of the average attribute scores for each project was calculated. These project scores were then to be used to evaluate and rank the projects.

The results of this study indicate that the project scores (i.e., the product of the average attribute scores) do not satisfactorily predict the final project selection decision.

Alternate scoring systems, based on discriminant analysis, were developed in an attempt to identify which combination of project attribute scores would yield a project score such that a satisfactory prediction of the final project selection decision could be made. Two scoring systems were found to significantly improve predictability. In addition, both of these new scoring systems resulted in a notable reduction in the required data.

An Experiment with a Project Selection Process

At a large capital goods manufacturing firm an experimental change to one of their R&D project selection processes was undertaken and evaluated.

Work at this field site began with frequent open-ended interviews between the company's director of exploratory research and our investigator. Twenty to thirty minute telephone interviews were held regularly once or twice a week for approximately three months. These were complemented by monthly face-to-face interviews. The purpose of these discussions was to identify the criteria employed by this decision-maker in arriving at project selection decisions. In a project-by-project review of the 1967 portfolio, variables consistently considered in the decision maker's evaluation thought processes were elicited. Subsequently, a form was developed which incorporated these criteria into a formal project selection model.

As the first phase of the study progressed, a concurrent effort was begun to develop a computer-based project selection technique. The program essentially combined probability estimates associated with possible outcome values assigned to each of the criteria for projects in the decision-maker's portfolio. Using a Monte Carlo simulation technique, the input values and probabilities specified by the decision-maker's staff provided an output which allowed them to identify explicitly the risk associated with potential project pay-offs. Together, the input format and the computer program were designed to help the decision-maker:

1. consider a wide range of possible outcomes for a given project,
2. interrelate various items of information relevant to his analysis of a particular program, and
3. appreciate the uncertainty inherent in each project, as well as facilitate the pinpointing of those elements most likely to "make or break" a project.

As part of a third phase, the decision-maker was able to use the input format and computer program to evaluate 31 projects accepted for funding in 1969.* Although this stage was aimed primarily at pilot testing and installation of a project selection system for later experimentation, a considerable amount of worthwhile data were obtained concerning the consequences of introducing a formal project selection technique.

* The decision-maker held small project review meetings in which 4-8 persons responsible for a project were asked to jointly supply necessary data.

For example, nearly all of the participants from the decision-maker's staff welcomed the opportunity to explicitly indicate the uncertainty in their estimates through the mechanism of associating probabilities with projected outcomes. A significant percentage, however, encountered extreme difficulty in translating their intuitive feelings into actual estimates.

Also, there were some so-called "eye-openers" concerning the consequences of several projects. Two projects were dropped on the recommendations of the individual proposers in light of their analysis using the new project selection system. Another project's research strategy underwent serious revision based upon the results of several sensitivity analyses made possible by the computerized technique.

Next, the new procedure was experimentally incorporated into the company's actual exploratory research project selection decision process. In total, 69 persons participated in a total of 105 evaluations using the new procedure. Each evaluation required 1 1/2 to 2 hours from each participant.

Finally, 64 of the 69 persons using the new procedure were interviewed and asked to complete a questionnaire. This data was used to assess their willingness to adopt the new procedure and served as a basis for pursuing reasons for this willingness or lack of willingness to adopt such a procedure.

The results of this study indicate that there were at least three major determinants of an individual's attitude towards the use of the procedures. These variables involved the individual's perceptions of:

1. the value of the data generated by the technique,
2. the appropriateness of the information considered by the organization during the project review process, and
3. the value of changes in projects' research strategies attributable to the use of the formal technique.

The results further indicate that an individual's perceived need for additional information was greatly increased because the technique was used and that individuals indicated that they acquired more information because the technique was used. However, 27 of the 64 respondents indicated that their acquisition of additional information was seriously inhibited by the lack of an appropriate

mechanism for acquiring information. Many of these respondents attempted to acquire additional information and found that relevant information did not exist. Others found difficulty obtaining information due to the difficulties in crossing organizational boundaries and a general unwillingness to part with potentially relevant data by those who were presumed to have the necessary data.

Some Specifications for a Real-Time Information System

Approximately 40 managers of R&D organizations have cooperated with us in an attempt to set forth some preliminary specifications for a real-time system. These managers, working in one of four, three month seminars on R&D management, have prepared design specifications for an information and computational system that would be of value to their organizations.

Drawing upon this reservoir of experience and data, two studies were initiated. The first study attempted to identify the basic structure for a system which would satisfy all or part of the requirements set forth by this group of managers. In addition, an attempt was made to compare the objectives and requirements among the individual systems.

Results from the first study indicate that a batch processing system would satisfactorily accommodate the immediate needs of these managers. Regarding the internally generated data (e.g., project costs, progress, and budgeting information) the basic data structure and process requirements were in general uniformly and clearly defined. Similarly, the requirements for external data (e.g., market data) were in general uniformly and clearly defined. However, the requirements necessary to effectively relate these two sets of data, and items within these packages, could not be adequately specified.

The second study attempted to examine some of the problems associated with incorporating soft, or somewhat less factual data, into an information system. This data included such items as management's insights into causal relationships in the market place and management's judgments concerning the probability of uncertain events.

The results of this study indicate that such organizational functions as assessing the relevancy of data for a particular decision situation and the function

of deliberating over a best course of action among alternatives must be given further consideration. The first function was further identified as one which would involve the allocation of responsibility for validating and packaging relevant information. The second function was further identified as one which would involve processes that might result in a more systematic ordering of management's deliberation process.

Progress at Two Government Facilities

Two studies are in progress at two government R&D facilities. The study at the first site has been limited to descriptive aspects of the project selection process while the study at the second site has been directed toward the development of a series of experiments with the project selection process.

As part of the first study, a set of data has been acquired which comprises laboratory reports and review sheets for all projects proposed in that facility, over a period of four years. This documentation represents the core information to which certain criteria are applied in arriving at project selection decisions. In addition, a set of instruments has been designed for further research in this laboratory. This instrument package has been designed for the purpose of monitoring such aspects of the project selection process as the time at which decisions are made, the content of the decisions, and the criteria and premises upon which decisions are based.

The second study was undertaken with the intention of designing a series of field experiments. This series of experiments will involve assessing the relative adequacy of a number of formal project selection and allocation methods. This assessment will be made by including, on an experimental basis, relevant methods into the organization's R&D project selection process.

At present, in depth interviews with responsible decision makers have been completed and an attempt is being made to make a preliminary statement of the decision problem. Concurrently, the feasibility of evaluating several model forms are being pursued. The model forms include constrained capital budgeting models, modified scoring models, and heuristic decision rules.

Some Tentative Conclusions

The results of this research project indicate that much of the information required for either a descriptive or prescriptive analysis of the project selection process is not collected or even recorded by most R&D organizations. Consequently a variety of methods--interviews, observations, and questionnaires--must be used to obtain appropriate information. Accordingly, the development of means of collecting, reducing, and evaluating these kinds of data must continue to be an integral part of our research activities.

Our research on scoring models and preference functions indicate that such model forms do not offer a satisfactory means for discriminating among research projects. This research has led to a realization that attempts must be made to further examine the methodological and theoretical structures upon which present models are based.

Results further suggest that prescriptive and descriptive models of the R&D project selection process must take explicit account of the probabilistic nature of the R&D process. Accordingly, our future efforts will be concerned with the treatment to be given probabilistic data that can be collected and its relationship to the data called for by formal decision models.

Our experiments with the use of formal project selection techniques in organizations has led us to believe that the use of such techniques may result in changes to a number of organization and organizational variables. For instance, our results suggest that new and different information is considered by an organization when a formal decision model is used and that the objectives and activities associated with a research project can also be affected. Our plan is to further examine the consequences of using formal decision models upon such variables.

Finally, our exploration of the design requirements for a real-time information and computational system to assist R&D management in their project selection decision-making will continue to be pursued along the dimensions already discussed. However, our research further indicates a need to investigate the problems related to the estimating of project attributes. Accordingly, a series of studies are being planned with the objective of examining problems related

to estimation (69/D). Some of the questions asked in this study are: What is the relative importance of those factors judged to be relevant to the technical success of a research project? What factors appear to best characterize estimates made by individual estimators? What factors appear to characterize the reliability of an estimator?

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- 69/D (Draft) Hans-Horst Schroeder, "Problems Related to the Estimating of Project Attributes," Department of Industrial Engineering and Management Sciences, Northwestern University.
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